

MARS PATHFINDER'S LESSONS LEARNED: From the Mars Pathfinder Project Manager's Perspective: The Future Road. A.J.Spear, R.C.Anderson, B.Muirhead, N.Haynes, and G.Cunningham, Jet Propulsion Laboratory, Pasadena, CA 91109.

Introduction

In 1992, Dr. Wes Huntress challenged the JPL staff to undertake the first of NASA's new Discovery program missions; Pathfinder. Fundamentally different than past JPL planetary missions, both the budget and schedule were fixed; the Pathfinder Flight System development was fixed at \$171 million, \$25 million was allocated for development of a Rover, and the schedule was fixed at 3 years. Thus the term "faster, cheaper, and better" began. At the first IAA Conference on Low Cost Missions, I boldly presented our Plan. There were smiles. At the second conference, with building confidence, but with more weight on my shoulders, I presented status against this Plan. At the time we looked good, but we had a long way to go. Again, there were smiles.

This time, it's with great pleasure and relief that I present not theory any longer, but successful Mission results--and with our original Plan maintained throughout the Project largely in tact. There will be different smiles now.

Objectives:

The primary objectives of the Pathfinder mission was to land an operating spacecraft to the surface of Mars using a new type of landing system. Most skeptics thought it was a crazy idea and probably should not be attempted. But not everyone agreed with this assessment and the Project Managers Tony Spear and Brian Muirhead pulled together a team of highly qualified people to meet this challenge.

One thing that actually helped the Pathfinder team with their task was the clearly established mission objectives. The team was given the task of accomplishing the following things within the budget and schedule constraints of the project:

- Demonstrate a simple, reliable and low cost landing system for placing science payloads on the surface of Mars.
- Demonstrate NASA's commitment to low cost planetary exploration.
- Demonstrate the mobility and usefulness of a microrover on the surface of Mars.
- Assess the structure of the Martian atmosphere, determine elemental composition of rocks and soil, investigate surface geology and mineralogy of rocks and acquire meteorology data at the surface.

So, the Pathfinder team undertook this massive challenge knowing full well that it would require a different way of doing business here at JPL. The challenge of the financial and schedule constraints, the opportunity to demonstrate that anything was possible, and the excitement associated with building something that was going to land on Mars brought together the right team of people to accomplish the task. In fact, the opportunity to undertake a this task cost less than the making of the movie Titanic and had the potential to have a much better ending was a challenge that the team agreed was well worth the risk.

Advantages of a Faster, Cheaper, Better Approach

The following are key elements of the management approach used on the Mars Pathfinder mission.

1) The Team

The Pathfinder team consisted of JPL, NASA and contractor personnel who were highly skilled and committed to the success of the mission and to each other. Excitement about the mission, the challenge of new ways of doing business and the willingness to give people lots of authority/responsibility attracted many of JPL's best and brightest. Pathfinder team had the talent, management trusted the workers and the workers trusted the management and all were committed to the success of the mission. This was also true with our contractors and the NASA centers that supported the mission. JPL's NASA's system of hands-on, cradle-to-grave responsibility was alive and working well on Pathfinder, management had created the ultimate family atmosphere.

2) Achieve upfront agreements, maintain them.

Pathfinder was successful in defining a meaningful Mission scope under the cost cap, getting this scope sold for Project development, and then maintaining this original scope. The major change was the addition of the rover, whose development was funded separately.

A major success with the rover effort was the development of a close working relationship between the lander and rover teams. The teams worked closely in both design, assembly, integration and test, a major factor in our relatively smooth pre-launch integration activities and flight operations.

NASA was successful in providing the development funding on the profile we needed, on streamlining the lander camera AO, and standing back and empowering us to do our challenging job at hand. This NASA support was essential.

3) Taking Risk

With many low cost Missions flying in all directions in the Solar System, an occasional failure is tolerable--but while this may be true at the NASA level, its not true for an individual Flight Project. At the Project level, each must succeed!

In a framework of an old, rigid system, taking risks can lead to an increased probability of failure. The secret to success in the Pathfinder environment of faster, cheaper, better constraints was to take risks smartly and find clever ways to mitigate the risks by doing things differently. Part of Pathfinder's success came from an early designation as a Class C project. This meant that only certain rules in the existing JPL rule book had to be followed. For example, we didn't have to do full failure modes and effects analysis of every element of the spacecraft. Instead, we did a high level analysis and focused our limited time and resources on the weak links. This approach put the responsibility for success directly in the hands of the front line engineers; they felt personally responsible for making the system reliable. They weren't counting on the blind application of some practice that, once completed, they could walk away from and say the job was done. In fact, this personal sense of responsibility for reliability, meant the job wasn't done until we arrived safely on Mars.

4) *Streamline QA*

We asked that Pathfinder be given the charter to establish a FCB QA approach for small JPL Missions. This was granted and we proceeded to do this in conjunction with the Institutional Quality Assurance Office here at the Lab, dumping the established "Green Book," which was used on big Projects.

While we were designated a Class C Mission, we made sure we did the essential Class A QA work across the whole spacecraft: the cruise stage, lander and rover. In particular, we took no shortcuts in TESTING. Our major reduction in QA scope dealt with reductions in paper and tractability.

Contrary to what you may have heard, there were no "Radio Shack" parts used in the flight gear. All parts, including commercial parts, were thoroughly inspected, tested, and qualified for space.

The QA people working on Mars Pathfinder were also colocated with the engineers and both worked hard and hand together to build into the spacecraft the most reliability at the lowest component level.

hand in hand

5) *Communication.*

The most important feature of Pathfinder's approach is collocation of all key team members on the same floor of one building around the JPL Test Bed. Communication is much more than meetings, memos and Email. We colocated about 100 engineers on the single floor of an open landscaped building. The view of some managers at JPL who think that collocation is over rated are not speaking from experience. Collocation simplifies lines of communication and facilitates rapid iteration of requirements, and resolution of issues and problems. Issues got resolved on the spot with all the appropriate hands involved in the meetings. We no longer tolerated IOM's being circulated in the Lab mail, requesting a response to a problem. In the past, it would take weeks to get answers, especially from those in buildings scattered across the Lab. Things like "meeting minutes" were also taboo.

6) *Hands-on management*

Pathfinder was blessed with excellent leadership. An in depth understanding by the Project leadership of the technical design, programmatic resources, and margins (especially mass) allowed for rapid decision making. The skill of managing critical resources such as money and schedule reserves was critical to the success of the project. The decision makers were close enough to the real action that extensive trade studies, which cost time and money, were not needed to make baseline changes. Meetings were open to all members of the team and were used to make many decisions; sometimes occurring spontaneously in the halls.

During the critical integration and test (I & T) phase, when time and money were running out, the Project operated without individual work definition packages and instead relied on project level detailed test schedules, workforce plans and lien lists to track progress and budget. Hands-on leadership and microknowledge allowed this approach to work without destroying the established schedule or budget.

7) Starting with Adequate Reserves

This we did by carefully scoping the Mission properly at the outset. We could have flown more science, for instance, or more redundancy. We looked at flying a seismometer and instruments to detect Hydrogen and soil toxicity, but we backed off.

8) Openness and honesty

The Project leadership set the example of how the Project operated. The example was openness, honesty and integrity with a big dose of humor. An atmosphere of openness, honesty and personal responsibility by every member of the Pathfinder Team was essential to our success throughout all phases of development and operations. This spirit started at the top. The Project leaders set the tone of how the team worked together by dealing straight with each other and not playing games. For example, when the Flight System was struggling to determine whether it could afford \$300K for GaAs cells for the lander, Al Sacks, the Ground Data System Manager, offered up \$300K from his accounts. Al knew it would save the project money later on if we didn't have to power manage during the surface operations phase. This was a great example of the kind of teamwork that happened throughout the development.

Integrity and openness also allows mistakes to be identified and corrected quickly. The flat organization structure also fostered a sense of trust and confidence between management and team members.

9) Members of a team

Here again Management, JPL and contractor, sets the tone of how well this kind of cooperative atmosphere develops and works; everyone, no matter what their job detailed was part of a team. Small companies were particularly well attuned to this approach and felt just as much pride in the mission all the way to the end.

10) Generalists versus Specialists

The technical world of engineers can be divided into 2 groups, generalists and specialists. The tendency in the recent past has been to favor specialists over generalists. Specialists are highly skilled individuals in a relatively narrow area of expertise. However, it can take a small army of specialists to cover a complex system. On the other hand a small group of experienced generalists can cover a lot of ground and tap on the specialists as needed. The need for generalists to glue a complex system together was particularly true for EDL and science. A good generalist knows to look beyond their own immediate area of concentration. They know that their systems must interface with something and therefore we encouraged them to look over the fence into the other guy's area. Without exception it derailed some misunderstanding that if not identified early would have led to an expensive and/or time consuming problem. ()

11) Creating momentum

Most of the time project leaders were forced to make important decisions based on imperfect, limited and even non-existent information and often on very short notice. On Pathfinder we had to keep moving, stopping and studying a problem to death was not an option and not our style. The Project leadership was close to the action, experienced and were not afraid to make quick decisions and were not afraid to admit and correct mistakes. Project leaders kept watch on the results of all decisions, listened to the implementers, and, if necessary, were not afraid of making mid-course corrections.

12) Set high standards.

Forming and maintaining a highly spirited Team is not a trivial task. Big ego's come with smart people. The challenge lies with bringing them together as a Team. The project had to let go a number of people (30%) during the course of the mission who were not up to the standards needed to make the project successful. Due to the limited funds and time, FCB projects cannot accept under-skilled, bad attitude or untrustworthy people. There is nothing more damaging to a team's spirit than seeing management tolerating someone who is not pulling their weight. Change must be done quickly and with sensitivity in the interests of both parties. Because our leaders were constantly on the front line, these problems were usually discovered early and easily corrected.

13) Keep your eyes on the prize.

Like most complex flight projects, planetary missions have a tradition of long development cycles and requiring a lot of people who are highly motivated and contain diverse skills and backgrounds. When problems arise, it is very tempting to focus on intermediate solutions. By doing this, it is very easy to create an environment where one group can complete their individual goals without overall success, which can not be accepted with the FCB approach. It doesn't matter if individual systems of the spacecraft work, if the mission fails. Our "big hat" approach was very powerful because it made everyone responsible for the success of the mission. Everyone, whether hardware engineer, analyst or manager, must wear the bigger system hat and look beyond his own interface/specialty to be sure he understands the other guys problems/questions.

14) Outreach to the Public

The public is the ultimate customers. When the word came down from NASA that all Projects need to do Outreach, we jumped on it, "pathfinding" an effective approach which leveraged our meager resources through Teaming arrangements with universities--about a dozen of them spread out throughout the U.S.

With relatively little money, the university professors and students got "the word" from us, learned about Pathfinder, the Mars Program, and other NASA Missions. Members of the Mars Pathfinder Team, "deputized" to do outreach in their spare time, taught the university team members. Then, they went out and spread "the word" to middle school kids and the public in general in their community.

Also, we embraced the concept of immediate release of our mission data on the Internet--which we did, but not without protest from some of our scientists, initially. This immediate release of our data paid off big, and we now hold the record on the number of "hits" to a webpage.

Mars Pathfinder Major Contributions to Future Missions

Mars Pathfinder major contributions to future landers are designs, developments, and lessons learned. In particular, the Mars Pathfinder project:

- demonstrated a low cost, fast track project implementation approach.
- demonstrated a new, low cost, robust passive entry system capable of landing in a variety of terrains.

- developed a self-contained flight system architecture built around a state of the art central computer.
- developed a powerful, multi-spectral surface imager with stereo capabilities.
- demonstrated the feasibility of a free ranging, autonomous navigating rover .
- demonstrated the feasibility of using solar power.
- demonstrated just how powerful the internet could be for public outreach.

The Future for Deep Space, Robotic Missions: “ Mars Pathfinder is the last of the cowboys relative to the road ahead”.

It's one thing to do an experiment, employing new approaches at the “one Project” scale, it's another to institutionalize them. In its re-engineering of itself, JPL is studying Mars Pathfinder approaches, incorporating those that are appropriate.

Mars Pathfinder, given license, was “free to roam,” to experiment with new approaches -- nice. However, it was out there on the “range” all alone inventing air bags, its flight computer, the rover on the fly, under a cost cap, on a quick reaction schedule--not so nice.

In the future, with JPL's process oriented approach, smaller Project Core Teams, still with ultimate Mission responsibility, will be supported by multi-mission expert teams, the latest CAD tools, inventories of long lead equipment, and powerful advanced technology acquired at low recurring cost.

In addition to FCB, a second important NASA thrust focuses on development of Advanced Technology which enables a much larger Mission Set for the available dollar resources. Spacecraft will be shrunk further in size requiring smaller and cheaper launch vehicles, capitalizing on commercial micro-electronics development -- towards a “spacecraft on a chip” -- towards a “surface lab on a chip”.

Programs of Projects are being planned so that these Advanced Developments, from chips to flight-ground systems, are used more cost effectively by many Missions, eliminating duplication, re-invention.

Individual Projects no longer will be in the business of developing their individual data systems; their radio links; their flight and ground computer systems; their propulsion systems; their power systems; their modular, multifunctional structures; many of their instruments which will be integrated with engineering subsystems; and very importantly, their computer operating systems and other generic, flight-ground software. All of this will be furnished to them by the multi-mission advanced development processes.

Software being developed now at the Program level across many Missions, will be delivered to the individual Projects at low cost--and hopefully, more “bug free”. And with the advances in spacecraft computer power, spacecraft autonomy will advance towards a “thinking spacecraft”.

When I was young, I used to hike in the mountains. Now older I use my four wheel drive to get to these high places. Likewise, Projects will no longer need to build up their “Ford Explorers”, assembling the chassis, motor, transmission, etc. They will get their Ford Explorer fully assembled, so they can concentrate on “Exploring” and what cargo to take with them.

WHAT AN EXCITING FUTURE!